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AN EXPERIMENTAL METHOD OF DETERMINING
BALLISTIC DENSITIES MAKING DIRECT USE OF SIRS RADIANCES

by

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ABSTRACT

A technique for calculating ballistic density from Satellite Infrared Spectrometer (SIRS) radiance data has been developed and evaluated. The experiments with both simulated radiances and real-time radiances show the technique has considerable skill in computing ballistic density.

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ABSTRACT

A technique for calculating ballistic density from Satellite Infrared Spectrometer (SIRS) radiance data is described. A model experiment in which radiance values are calculated from the temperature sounding is used to verify the technique. In a second experiment real-time SIRS radiances were used with synoptic and geographically-consistent soundings for evaluation of the ballistic density. For the limited data sample tested, the technique of computing ballistic densities from satellite radiances is capable of matching those computed from conventional radiosondes.

1. Introduction

The success of the temperature profile determination technique (Smith, et. al., 1970) from the Satellite InfaRed Spectrometer (SIRS) data has important implications for ballistic calculations. Availability of these complete soundings allow calculation of ballistic parameters in remote regions without radiosonde soundings. However Commander K. Ruggles noticed an analog between the "weighting functions" for the SIRS channels and the ballistic density weighting function. The SIRS "weighting function" is the logarithmic pressure derivative of the transmissivity (τ) of the atmosphere for that wavelength. These curves of $d\tau/d \ln p$ are exact for the partial pressure of CO_2 and are related to the total pressure through the constant mixing ration of CO_2. The similarity of the ballistic and transmissivity weighting functions suggests that the ballistic density might be determined directly from the radiance values. Ruggles (see Appendix A) has developed mathematical relations that illustrate the analogy, and give a basis for a direct statistical determination of the ballistic density from SIRS radiances. The objective of this research is to verify the suggested technique.

The first check of the technique used 100 soundings (Wark, et. al., 1962: Appendix A). The radiance in each channel which the satellite would detect was computed for each temperature sounding using

$$I(\nu_i) = B[\nu_i, T(p_s)]\ \tau\,(\nu_i, p_s) - \int_1^{\tau(\nu_i, p_s)} B[\nu_i, T(p)]\ d\tau(\nu_i, p) \qquad (1)$$

with the Planck function

$$B[\nu, T(p)] = \frac{C_1 \nu^3}{\exp\left[\frac{C_2 \nu}{T(p)}\right] - 1} \qquad (2)$$

where $C_1 = 1.19064 \times 10^{-5}$ erg cm^2 sec^{-1} (ster)$^{-1}$

$C_2 = 1.4387$ cm ^oK

In these expressions ν is the reciprocal of the wavelength and T is the temperature. Details of the radiance calculations are described in Appendix B.

Values of the ballistic density were also computed for each of the temperature profiles. The ballistic density was defined

$$\rho_B = \frac{\int_o^{z_T} \frac{\rho(z)}{\rho_s(z)} \; F_\rho(z)\, dz}{\int_o^{z_T} F_\rho(z)\, dz} \tag{3}$$

where $\rho_s(z)$ is the density distribution of the standard atmosphere at 45N for January, $F_\rho(z)$ is the ballistic weighting function which was taken from Fig. 16b of Finke (1969), and Z_T was 66.5 km. Further discussion of the ballistic density calculation is given in Appendix C.

Corresponding values of ρ_B and the simulated radiances at the eight SIRS wavelengths were statistically screened with the BIMED 02R package (Dixon, 1966) using 50 soundings for the dependent sample. The coefficients $a(\nu_i)$ in the resulting linear expression

$$\rho_B = a_o + \sum_{i=1}^{8} a(\nu_i)\; I(\nu_i) \tag{4}$$

were statistically checked against the data sample ρ_B, I_1, ..., I_8 resulting from the 50 independent soundings. From this first, or simulated, approach it was determined that the coefficients in the regression Eq. (4) could be obtained with a high degree of stability.

In view of the successful verification with simulated radiances of the mathematical-statistical approach suggested by Ruggles, a second check of the technique was undertaken using real-time SIRS radiances in conjunction with synoptic and geographically-consistent soundings for evaluation of the ballistic density. The general approach was to evaluate the ballistic densities with Eq. (3), interpolate to the sub-satellite point, and statistically screen as before to obtain a relation as in Eq. (4). The regression coefficients again showed considerable stability. However the so-called factor-method of obtaining orthogonalized combinations of the I_1, ..., I_8 as predictors for day-to-day use will also be checked for improved stability of the coefficients.

2. Results with Model Atmospheres

The test with model atmosphere soundings from Wark, et. al. (1962) is indicative of results to be expected with no cloud contamination effects.

Temporal and spatial differences between satellite and radiosonde soundings are also eliminated by computing the radiances directly from the temperature soundings. The transmissivities τ for eight channels centered at 899, 750, 714, 706, 699, 692, 677, 669 cm^{-1} for use in Eq. (1) and Eq. (2) were provided by courtesy of Dr. W. L. Smith of NOAA.

Application of the stepwise regression procedure to $y_1 = (\rho_B - 1) \times 10^3$ as predictand and to the computed radiances for the 50 soundings in the dependent set as predictors led to the equation

$$\begin{aligned} y_1 = 226.26 &+ .04878X_1 - 1.29215X_3 + .580582X_4 \\ &- 1.22287X_6 + .46124X_7 + .07099X_8 \end{aligned} \qquad (5)$$

Here X_i is the factor π times the radiance in the i^{th} channel, beginning with 899 cm^{-1}. The multiple correlation coefficient of Eq. (5) is .9978 indicating the right side of (5) accounts for 99.56 percent of the variance of y_1. The two variables X_2 and X_5 were statistically redundant and were screened out of (5). Supplemental stepwise regression equations relating X_2 to the remainder of the predictors resulted in a multiple correlation coefficient of .999. An identical result was obtained using X_5 with the other predictors in Eq. (5). Thus inclusion of X_2 or X_5 could provide no additional information above that provided by the six-predictor Eq. (5).

A summary of the statistics for the two sets of model atmospheres is given in Table 1. The multiple correlation using the soundings of the

TABLE 1. Effectiveness of Eq. (5) when used in the dependent and independent samples.

	Samples Mean ρ_B	Std Dev of Sample	Multiple R	%Expl. Variance	Std Error of Estimate	Max Error of Estimate
Dep (n = 50)	.98657	.02380	.9978	99.56	.00168	.00358
Indep (n = 50)	.98296	.02319	.9942	98.83	.00253	.00689

independent sample to compute the X_i on the right side of Eq. (5) was .9942. This means the prediction equation proved to be extremely stable when tested against the independent samples, as 98.83 percent of the variance was explained. Both the standard error and the maximum error of the estimates increased in the independent sample. However the values are rather small compared to the standard deviation of the sample. The capability of explaining a large fraction of the variation and small standard error in the simulation experiment certainly justifies the extension to operational SIRS radiances.

3. Results with Actual SIRS Data

In this phase of the research, actual values of SIRS-A radiances were used rather than computed values. The observed radiance values include contributions from clouds in the field-of-view of the SIRS spectrometer, "Clear-column" radiances obtained by adjustment for cloud contamination were provided by Dr. H. Woolf of NESC. Radiosonde soundings (1200 GMT) over Eurasia for a two-week period were provided by P. Lowe of NWRF. Eight days with corresponding radiance and radiosonde data were available. Unfortunately there was a two-day data gap between the four-day periods, December 27-30, 1969 and January 2-5, 1970. The first period was in the early stages of a stratospheric warming that was well-established by the end of the second period.

Fields of ballistic density computed from Eq. (3) were analyzed from 1200 GMT soundings, and values were extracted at the locations of the satellite radiance data. Radiosonde data lagged some of the SIRS observations by up to four hours. However these lags were accepted to provide sufficient data for statistical tests. On any one day the number of scan spots, and of corresponding ρ_B, varied from 15 to 24. Thus for a statistically suitable dependent sample, it was necessary to pool the data of the first three days of each period. Data from the fourth day was used as the independent test of the regression equation. Because of the data gap, only two such independent tests were possible, rather than the optimum of seven tests, if no gap existed.

Another source of unreliability might occur from a bias introduced by the correction of the observed radiances for cloud contamination. While the details are not important here, it should be noted that the Smith (1970) scheme for removing cloud effects uses information from three of the eight channels. An iterative scheme is used which determines the elevation of cloud layers and their amounts. The procedure minimized the difference between the actual radiance and an equivalent clear-column radiance. If the iterative scheme suggests nearly overcast conditions at upper levels, the sounding is tagged as being less reliable. Nevertheless for the current research all reported equivalent clear-column radiances were accepted as valid.

For both data periods the first three days provided a stepwise-screened regression equation, much like Eq. (5). Only five channels were significant in each case when the critical F-test of Miller (1962) was used. The predictors X_1, X_2, X_3, X_5 and X_8 provided the best set of five-predictor equations, and the best verification when applied to the independent samples of data. The results of the tests are summarized in Table 2.

TABLE 2. Statistics of the three-day dependent prediction equation and resulting verification on the fourth day in each period (predictors X_1, X_2, X_3, X_5, X_8).

Period	Mean ρ_B	Std Dev ρ_B	Multiple R	% Expl Variance	Std Error of Estimate	Max Error of Estimate
I. Dep (n = 54)	1.01463	.00955	.8832	78.00	.00482	.01022
I. Indep (n = 24)	1.01821	.01159	.9382	88.02	.00398	.00816
II. Dep (n = 69)	1.01638	.01616	.9819	96.42	.00318	.00996
II. Indep (n = 16)	1.01062	.01865	.9636	92.85	.00516	.01107

The best results were obtained in the second period with a multiple correlation approaching those found in the simulation experiment (Table 1). The standard error is also increased to .003 - .005, or a percentage error in determining the integrated ballistic density of only .3 to .5 percent. It should be noted in Table 2 that the dependent regression equation in the first period explained only 78 percent of the variance in ρ_B. However the explained variance using this same equation as an estimator in the independent test improved to 88 percent. This improvement could have resulted from relatively less noise arising from error sources described above. Another possible interpretation is that density changes accompanying the stratospheric warming were subject to a relatively large temporal variation during the three days comprising the dependent sample.

4. Conclusions

The experience with the actual data suggests difficulty in interpolating the ballistic density values closer than $\pm$ .003 with good radiosonde soundings. About one half of the European soundings either terminated in the troposphere, or were missing data at various levels. This difficulty in specifying the dependent data, especially with the time lags involved, also affects the results of this research. Nevertheless the indication is that the technique of computing ballistic densities from satellite radiances is capable of matching those computed from conventional radiosondes. Standard errors of the estimates are of the same order as the accuracy of analyzing the ballistic density field.

Some of the errors in the estimate of ballistic density may be attributed to the uncertainty in the cloud contamination correction. If such a bias does exist, and could be reduced or eliminated, the results with the simplified soundings would be indicative of the potential accuracy of the statistical technique. The results suggest that as few as five channels might be required if the statistical technique was adopted. However with the present instrument the remaining three channels are necessary to remove cloud contamination effects.

5. Suggestions for Further Research

Ruggles also suggested (see development in Appendix A) that a ballistic wind vector $\bar{B}_V$ could be statistically determined using radiances in gradient form

$$\bar{B}_V = \frac{g}{f} \mathbb{k} \times \nabla_H \left(\sum_{i=1}^{B} b_i I_i \right) \tag{6}$$

In this equation g is the acceleration of gravity, f is the Coriolis parameter, ∇_H is the horizontal del operator, and the new regression coefficients b_i would be calculated as above for the ballistic density.

With the present NIMBUS III data spaced nearly 30 degrees in longitude, either the ballistic zonal wind component or that normal to the path of the satellite could be determined. The requirement for specifying gradients in Eq. (6) greatly reduced the number of samples available for a statistical test. A more complete test for the ballistic wind is recommended with data over North America to ensure sufficient rawinsonde coverage of a high quality. It is recommended that "simultaneous" rawinsonde and SIRS-B data be obtained during the transition period from summer stratospheric easterlies to autumn westerlies. Availability of rocketsonde data for use in continuing the wind profile to upper levels is considered mandatory. It may be necessary and advisable to interpolate in both space and time to obtain adequate data for use in Eq. (6). A SIRS-B data sample having lateral scan information would allow computation of the meridional component as well.

The expression within parentheses in (6) can be interpreted as an "equivalent ballistic geopotential", that is, the integral of the geopotential weighted by the ballistic wind weighting function. Since gradients of the geopotential are desired, the actual values of the geopotential may be replaced by deviations from the standard heights to reduce the truncation error of the integral. Some verification of this "equivalent ballistic D value" approach is given in Table 3, which refers again to the simulated data. It should be noted that only the D values in the free atmosphere are included; the surface pressure is assumed to be the standard value. A surface pressure analysis would be necessary to "anchor" the statistical estimation of the "ballistic D value".

TABLE 3. Effectiveness of statistically determining equivalent ballistic D values (meters) from simulated radiances.

Sample	Mean D	Std Dev of D	Multiple R	% Expl. Variance	Std. Error of Estimate	Max Error of Estimate
Dep (n = 50)	146.47	336.60	.9981	99.62	22.28	95.52
Indep (n = 50)	209.73	292.70	.9978	99.56	19.58	52.98

At least for these simulated radiances the stability of the regression coefficients is quite high as more than 99 percent of the variance is explained in the independent sample. In addition the standard error of the estimate is 20 meters, which is quite low. Of course it is the gradient of the ballistic D value which is required in Eq. (6), and the error might be larger when adjacent soundings are used. Tests with actual radiance data are necessary to check the consistency and the accuracy of the D values.

In the proposed extension of the research with new data, both the direct method with Eq. (6) and the indirect method using the ballistic D value are to be evaluated. The latter method is analogous to that presently used to compute ballistic winds from analyzed height fields. It allows a separate determination of the capability of determining ballistic wind components from a two-dimensional field of the integral of weighted geopotential.

In another aspect of the research, new regression techniques have been evolved, but have not yet been used. These new methods involve factor analysis and produce linear combinations of all eight of the clear-column radiances as predictors. The predictors thus formed are linearly independent of each other. This procedure has not been applied in the current study involving ρ_B , because we felt the standard stepwise regression analysis was sufficient vertification of the basic hypothesis. However the advantage of the factor analysis is that it gives a unique decomposition, and thus the coefficients should have greater temporal stability. The availability of the new statistical technique and of the new data should allow a more complete test of the applicability of satellite radiance data in determining ballistic density and wind.

Appendix A - Use of Atmospheric Infrared Spectroscopy for Ballistic Wind and Density Determination

after

CDR K. W. Ruggles (USN)

The application of atmospheric infrared spectroscopy to the ballistic wind and density determination problem is examined from a theoretical basis. The close relationship between the response function of the infrared satellite sounder and the atmospheric ballistics is shown.

Ballistic density for a vertical column of atmosphere can be expressed:

$$B_\rho = \frac{G(\rho_s)}{\ln P_{oo}} \int_o^{P_{oo}} \rho(\ln p)\, W_\rho(\ln p)\, d \ln p \qquad \text{1-A}$$

where:

B_ρ is the ballistic density of the atmosphere

$G(\rho_s)$ is a constant based on the ballistic characteristics of a standard atmosphere

$W_\rho(\ln p)$ is the missile density weighting factor

p is pressure

P_{oo} is the pressure at the surface of the earth.

In a similar fashion, a ballistic wind for a vertical column of atmosphere can be expressed:

$$B_v = \frac{1}{\ln p_{oo}} \int_o^{P_{oo}} \mathbb{V}\,(\ln p)\ W_v\,(\ln p)\ d \ln p \qquad \text{2-A}$$

where:

B_v is the ballistic wind of the atmosphere

$\mathbb{V}$ is the horizontal vector velocity

As a first approximation, we assume geostrophic flow. Equation 2-A then can be expressed:

$$B_V = \frac{1}{\ln p_{oo}} \int_o^{p_{oo}} \frac{g}{f} |k \times \nabla_H Z(x, y, \ln p) W_V(\ln p) d \ln p. \qquad 3\text{-A}$$

where g is the acceleration due to gravity, $\nabla_H Z$ is the horizontal gradient of height measured along a constant pressure surface, and f is the coriolis parameter. Regrouping and reorganizing, equation 3-A can be expressed:

$$B_V = \frac{g}{f \ln p_{oo}} |k \times \nabla_H \int_o^{p_{oo}} Z(x, y, \ln p) W_V(\ln p) d \ln p \qquad 4\text{-A}$$

Examining equation 1-A, we shall express the weighting function W_ρ as a linear combination of arbitrary functions, $F_i(\ln p)$ such that:

$$W_\rho(\ln p) = \sum_{i=1}^{N} a_i F_i(\ln p). \qquad 5\text{-A}$$

a_i are constants. At this point the constraints on $F_i(\ln p)$ are that they are functions of ln p, and they are known, fixed functions. In a similar fashion, we can express $\rho(\ln p)$ as a linear combination of arbitrary functions, $H_i(\ln p)$, such that:

$$\rho(\ln p) = \sum_{i=1}^{N} r_i H_i(x, y, \ln p). \qquad 6\text{-A}$$

where r_i are weighting constants. Substituting into equation 1-A and rearranging, we can write:

$$B_\rho = \frac{G}{\ln p_{oo}} \sum_{i=1}^{N} a_i r_i \int_o^{p_{oo}} H_i(\ln p) F_i(\ln p) d \ln p. \qquad 7\text{-A}$$

Following similar reasoning, equation 4-A can also be written:

$$B_V = \frac{g}{f \ln p_{oo}} |k \times \nabla_H \sum_{i=1}^{N} s_i b_i \int_o^{p_{oo}} H_i(x, y, \ln p) F_i(\ln p) d \ln p. \qquad 8\text{-A}$$

where b_i and s_i are scaling constants related to F_i and H_i respectively. Equations 7-A and 8-A are now in a form suitable for examination in comparison with the radiative transfer equation of interest.

A simplified form of the radiative transfer equation will be examined for one of the spectral intervals of a satellite spectrometer:

$$I_i = I_{o_i}\left[A,\ f,\ T(\ln p),\ \tau(\ln p)\right] + \int_{p_{oo}}^{o} B[f,\ T(\ln p)]\frac{d\tau}{d\ \ln p}\ d\ \ln p \qquad 9\text{-A}$$

where:

I_i is the intensity of radiation sensed by the i-th channel of the satellite spectrometer.

I_{o_i} is the contaminant intensity, such as the surface or clouds; and is a function of A, the amount of contaminant, f, the frequency of the i-th channel, and T(ln p) the temperature of the contaminant.

B[f,T(ln p)] is the Planck radiance at frequency f and temperature T.

τ(f, ln p) is the fractional transmittance of the atmosphere in the spectral interval centered at frequency f, and from pressure level p to the satellite.

Provided the cloud contaminant term can be evaluated and eliminated, equation 9-A reduces to:

$$I_i = \int_{p_{oo}}^{o} B_i[f,\ T(\ln p)]\ \frac{d\ \tau_i(f,\ \ln p)}{d\ \ln p}\ d\ \ln p \qquad 10\text{-A}$$

Using equation 5-A, we can express a ballistic weighting function as a linear combination of spectrometer weighting functions, such that:

$$F_i = \frac{d\ \tau_i}{d\ \ln p} \ .$$

Similarly, since B_i is a function of T, and therefore a function of Z or ρ, we can set:

$$H_i = B_i$$

Equation 10-A then becomes:

$$I_i = \int_{p_{oo}}^{o} H_i F_i\ d\ \ln p. \qquad 11\text{-A}$$

Substituting equation 11-A into equations 7-A and 8-A, we finally show that the ballistic density and wind may be directly expressed in terms of measured SIRS intensities; through the regression coefficients a_i and b_i, respectively, which follow:

$$B_\rho = G(\rho_s) \sum_{i=1}^{N} a_i r_i I_1 \qquad \text{12-A}$$

$$B_v = \frac{g}{f} k \times \nabla \sum_{i=1}^{N} b_i s_i I_i \qquad \text{13-A}$$

where N now is the number of radiometer channels used to determine the ballistic parameters.

Appendix B
Radiance Calculations with Known Model Soundings

The transmittances $\tau(\nu_i, p)$ for each of the eight SIRS channels are shown in the illustration in Table B-1. Transmittances for the seven channels in the CO_2 band were computed by Dr. W. L. Smith of NESC for pressure levels up to .01 mb. For the water vapor window channel, the transmittances was assumed equal to 1.0 above 200 mb and calculated from 200 mb to $p = p_s$ following Saiedy and Hilleary (1967)

$$\tau(899, p) = \exp\left[-\frac{1}{g}\int_{200}^{p} K\left(\frac{p}{1000}\right) q \, d\, p\right]$$

In this equation $K = .095 \text{ cm}^2\text{gm}^{-1}$ and q is the mixing ratio of water vapor. Transmittance values for this channel and one of the CO_2 channels are shown in Table B-1.

Temperature values were generally at mandatory reporting levels in the library of one hundred model atmospheres drawn from Wark et al (1962) for use in the simulation experiment. Any available significant level data was also used in linearly interpolating the temperature values to the pressure levels with τ values (see Table B-1), and the Planck function was calculated from Eq. (2) at each of these levels. The surface pressure (p_s) was taken to be 1000 mb, although the actual surface pressure was normally higher. Simpson's method of numerical integration was used in evaluating the integral term of Eq. (1) for the 34 layers between the pressure levels listed in Table B-1.

Although the model atmosphere soundings were carefully selected, few soundings reached above 10 mb. Above the final reporting level the temperatures were extrapolated following the January (45N) standard atmosphere lapse rate. This resulted in a uniformally warmer or colder atmosphere, but is probably not a serious error in the simulation experiment as both the radiances and the ballistic densities are calculated from the same sounding.

Table B-1

Transmittances for ν = 699 cm^{-1} and 899 cm^{-1}

Pressure (mb)	τ_{699}	τ_{899}	Pressure (mb)	τ_{699}
p_s = 1000	.0004	.9260	20	.9032
800	.0012	.9413	16	.9209
650	.0037	.9707	13	.9342
500	.0176	.9895	10	.9477
400	.0529	.9972	8	.9567
300	.1409	.9992	6.5	.9635
250	.2137	.9998	5	.9706
200	.3088	1.0	4	.9754
160	.4047		3	.9803
130	.4904		2.5	.9829
100	.5883		2	.9855
80	.6600		1.6	.9877
65	.7170		1.3	.9894
50	.7764		1.0	.9912
40	.8174		0.7	.9931
30	.8597		0.4	.9954
25	.8813		0.1	.9982
			0.07	.9986

Appendix C
Ballistic Density Calculations

The form of Eq. (3) for evaluating the ballistic density

$$\rho_B = \frac{\int_o^{z_T} \frac{\rho}{\rho_s} F_\rho(z)\, dz}{\int_o^{z_T} F_\rho(z)\, dz} \tag{3}$$

is essentially the same as that defined in Appendix A. Finke (1969) has deduced the weighting factor $F_\rho(z)$ for the re-entry vehicle of interest (see his Fig. 16b). The values of F_ρ were actually developed for 5000-ft intervals in the January standard atmosphere. An empirical function was used to fit these values and calculate F_ρ in layers bounded by mandatory pressure levels. The F_ρ values shown in Table C-1 are for layers between mandatory pressures and are normalized with the factor in the denominator of Eq. (3). As differences in layer thickness, computed from the hydrostatic equation, are included in this weighting factor, the values do not uniformally increase or decrease.

The mean density ρ in each of these layers is calculated from the temperatures (T_A, T_B) at the mandatory pressure reporting levels (P_A, P_B)

$$\rho = \frac{1}{2R_d}\left(\frac{P_A}{T_A} + \frac{P_B}{T_B}\right)$$

where R_d is the gas constant for dry air. Standard density values ρ_s for each layer are calculated from the same expression using the January (45N) Standard Atmosphere temperature values. Missing data at mandatory levels was interpolated from significant level data or adjacent mandatory level data. As was noted in Appendix B the data were extrapolated using the Standard Atmosphere lapse rate above the termination level of the sounding. This procedure produced a colder than normal sounding all the way to z_T if the last reported temperature was colder than normal. Some experimentation to improve estimate of densities above balloon termination levels is suggested, although F_ρ is quite small above 1.0 mb. The ballistic densities estimated by regression from the satellite-measured radiances will contain information from this layer and could lead to some bias. Soundings with surface pressure greater than 1000 mb were truncated at 1000 mb, while those with surface pressure less than 850 mb were rejected. Between these limits the temperature data were extrapolated to 1000 mb using the first two temperatures reported.

Table C-1

Normalized Ballistic Density Weighting Function F_ρ

Between Mandatory Pressure Levels Used in this Study

Pressure (mb)	F_ρ	Pressure (mb)	F_ρ
1000	.0273	20	.0224
850	.0470	10	.0090
700	.1368	7	.0065
500	.1083	5	.0072
400	.1334	3	.0040
300	.0811	2	.0042
250	.0074	1	.0014
200	.0807	0.7	.0009
150	.0857	0.5	.0009
100	.0554	0.3	.0004
70	.0394	0.2	.0005
50	.0427	0.1	.0001
30	.0273	0.07	
20			

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13. ABSTRACT

A technique for calculating ballistic density from Satellite Infrared Spectrometer (SIRS) radiance data is described. A model experiment in which radiance values are calculated from the temperature sounding is used to verify the technique. In a second experiment real-time SIRS radiances were used with synoptic and geographically-consistent soundings for evaluation of the ballistic density. For the limited data sample tested, the technique of computing ballistic densities from satellite radiances is capable of matching those computed from conventional radiosondes.

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